

Dileptons from Disoriented Chiral Condensates

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Disoriented chiral condensates are manifested as long-wavelength pionic oscillations and their interaction with the thermal environment can be a significant source of dileptons. We calculate the yield of such dilepton production within the linear sigma model. We find that the dilepton yield with invariant mass near and below $2m_\pi$ due to the soft pion modes can be up to two orders of magnitude larger than the corresponding equilibrium yield. We conclude with a discussion on how this enhancement can be detected by present dilepton experiments.

1. INTRODUCTION

Recently much attention has been devoted to the phenomenon of so called disoriented chiral condensates (DCC). (For a review see e.g. [1].) In this contribution we will show that the formation of DCC states in ultrarelativistic heavy ion collisions leads to a strong enhancement in the production of lepton pairs. The basic idea is that the formation of DCC states manifests itself in a strong amplification of low-momentum pion modes. Those may annihilate and give rise to strong enhancement in the production of dileptons within a rather narrow range in mass and momentum. This signal has the advantage that it is not subject to final state interaction such as hadronic signals for a DCC. The latter may be washed out due to re-scattering in the hadronic phase. A detailed discussion of the results presented here as well as all relevant references can be found in [2].

2. DILEPTON PRODUCTION

To leading order in the electromagnetic coupling we may assume that the dileptons are in asymptotic states. Therefore, the dilepton yield is given by the S matrices of the electromagnetic transition between different states [3],

$$\frac{dN_{\ell^+\ell^-}}{d^4q} = \frac{\alpha^2}{6\pi^3} \frac{1}{q^4} (q^\mu q^\nu - q^2 g^{\mu\nu}) \int d^4x d^4y e^{-iq \cdot (x-y)} \langle \hat{\rho} \hat{j}_\mu(x) \hat{j}_\nu^\dagger(y) \rangle, \quad (1)$$

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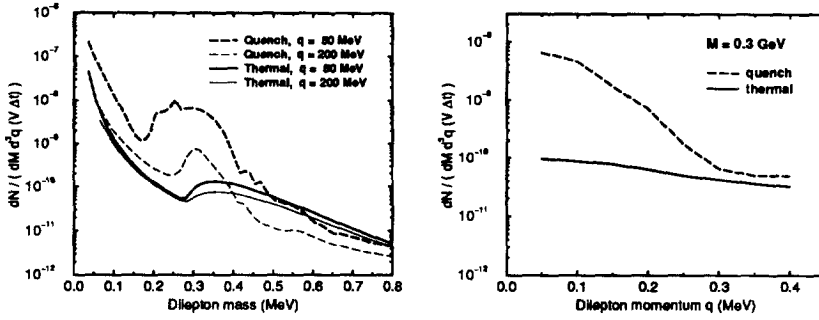


Figure 1. Left panel: Dilepton invariant mass spectra for thermal (full lines) and quench (dashed lines) initial conditions. Right panel: Momentum spectra for thermal and quench initial conditions for dilepton pairs of invariant mass $M = 300$ MeV. The result has been obtained in the $1/N$ mean-field approximation to the linear sigma model.

where we have summed over the final states and have assumed that the electron and positron are massless. (For details of the calculation see [2].) The dynamical input provided by the time-dependent solution of the linear sigma model enters in eq. (1) via the current-current correlation function $\langle \hat{\rho} \hat{j}_\mu(x) \hat{j}_\nu^\dagger(y) \rangle$.

We have calculated this correlation function in the $1/N$ mean-field approximation of the linear sigma model by Kluger et al. [4,5] as well as in the semi-classical treatment of Randrup [6]. In both model calculations, mean-field as well as semi-classical, we have calculated the dilepton yield for two different initial conditions with the *same* energy density, namely *thermal* and *quench* initial conditions. The latter lead to the formation of DCC states.

In the left panel of fig.1 we show the resulting dilepton invariant mass spectra for thermal and quench initial conditions for different three momenta of the virtual photon. Clearly a strong enhancement (factor $\simeq 100$) is seen around invariant masses of $\simeq 2m_\pi$. This enhancement is confined to small momenta, as can be seen in the right panel of fig.1 where we plot the dilepton momentum spectrum for pairs having invariant mass $M = 300$ MeV. A similar behavior is found in the semi-classical calculation [2]. There, the enhancement is somewhat smaller which is partially due to the additional mode mixing in the semi-classical treatment as well as the considerably larger grid size, which produces a faster damping of the low-momentum modes.

Based on a schematic model, where we have decoupled the low-momentum (DCC) modes from the high-momentum (thermal) modes, we were able to take approximate account of expansion by subjecting the DCC field to a boost-invariant Bjorken expansion. Also in this case we find an enhancement by more than an order of magnitude in the same mass region [2].

3. OBSERVATIONAL ASPECTS

So far we have established that the presence of DCC states leads to a strong enhancement of the dilepton production at invariant masses close to $M \simeq 2m_\pi$ and small momenta $p < 300$ MeV. The question of course remains to which extent this rather unique signal can be observed in an actual experiment, where other, more conventional sources may dominate the dilepton measurement. For the mass range under consideration the Dalitz decay of the η meson should be the most dominant background. Furthermore certain experimental acceptance cuts need to be applied. In order to estimate these various backgrounds, we have used a recent transport calculation for dilepton production for Pb+Pb collision at 156 AGeV [8]. This calculation contains among others the η -Dalitz decay channel as well as pion annihilation. In order to calculate the contribution from the pion annihilation on DCC states we have extracted from the above mean-field calculation the (mass and momentum dependent) ratio of quench to thermal dilepton production. We have then multiplied the dilepton yield from pion annihilation as obtained from the transport calculation with this ratio. This should then provide an estimate for the dilepton production due to DCC states in an actual heavy ion collision. This procedure of course ignores any non-thermal contributions as well as possible temperature dependences of the enhancement factor.

After applying the CERES [7] acceptance cuts the enhancement due to DCC states does *not* show up in the dilepton spectrum. The reason are the transverse momentum cuts, which reject all pairs where the transverse momentum of each individual lepton is below 200 MeV. However, there might be a possibility that for small invariant masses CERES can relax the transverse momentum cut to values as low as 60 MeV [9]. In this case the signal should be visible as shown in fig. 2 and clearly the signal is at least as large as the competing η -Dalitz decay. In the left panel we show the spectrum for all dileptons with transverse momentum smaller than 150 MeV. The right panel shows the dilepton mass spectrum for all transverse momenta.

This estimate started from the somewhat optimistic assumption that in each event the conditions for a quench are satisfied. However, if the system equilibrates in the high temperature phase and generates sufficient rapid expansion this assumption should be fulfilled to a large extent. Furthermore, we have not included any dissipative processes which could destroy the DCC states before the system has frozen out. Consequently if the lifetime of a DCC turns out to be considerably shorter than that of the system, our results have to be reduced accordingly.

4. SUMMARY

We have calculated the production of dileptons from disoriented chiral condensates using a quantum mean-field as well as a semi-classical treatment for the time evolution in the linear sigma model. We have compared the dilepton spectra obtained when using so called quench initial conditions, which lead to a strong enhancement of long wave length pion modes (DCC), with those obtained from thermal initial conditions. Compared to the thermal spectrum the quench initial conditions lead to a strong enhancement (factor 20 - 100 depending on the model) at an invariant mass of about $M \simeq 2m_\pi$. This enhancement is confined to dilepton momenta of $q \leq 300 - 500$ MeV and also rather narrow in invariant

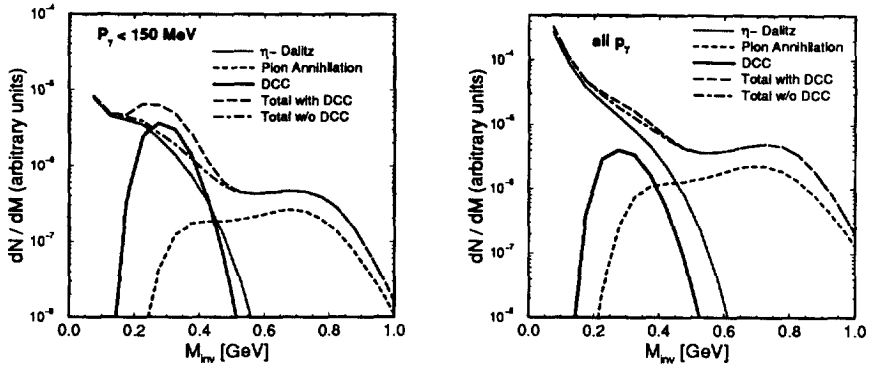


Figure 2. Dilepton invariant mass spectrum for Pb+Pb collisions at 158 AGeV after applying ‘CERES type’ acceptance cuts. Here the momentum cuts are lowered to 60 MeV. Shown are only the channels relevant for the discussion, but additional channels are taken into account in the total yield (see [8]).

mass. This enhancement seems to remain once expansion is taken into account.

As far as experimental observation of this enhancement is concerned, we have carried out a rough estimate of the expected signal for a Pb+Pb collision at SPS energies. We have shown that the signal would be strong enough to stand out from the main background, the Dalitz decay of the η -meson. We furthermore have applied the acceptance cuts of the CERES experiment. With the present cuts of $p_t > 200$ MeV the signal would not be visible by the CERES detector. However, if these cuts can be relaxed to $p_t > 60$ MeV, the signal should be observable.

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